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Table of Contents

CLIMATE CHANGE AND SUSTAINABILITY ENGINEERING IN ASEAN 2019

PREV NEXT

Conference date: 13 November 2019
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BROWSE VOLUMES

Free . October 2020

Attenuation performance of runoff storage basins within a moderate to steep slope urban catchment in Cebu, Philippines

Cristina L. Lalisan and Ricardo L. Fornis

AIP Conference Proceedings **2278**, 020002 (2020); https://doi.org/10.1063/5.0014958

SHOW ABSTRACT

Free . October 2020

Modelling road traffic accident rate and road geometric parameters relationship

Willy Kriswardhana, Akhmad Hasanuddin and Ibram Maulana Palestine

AIP Conference Proceedings **2278**, 020003 (2020); https://doi.org/10.1063/5.0014530

SHOW ABSTRACT

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Modelling the relationship between vehicle speed and road radius, degree of curved, and grade in Wringin Highway Bondowoso

Putra Cahayani, Willy Kriswardhana and Akhmad Hasanuddin

AIP Conference Proceedings **2278**, 020004 (2020); https://doi.org/10.1063/5.0014532

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Modelling Road Traffic Accident Rate and Road Geometric Parameters Relationship

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Abstract. Road geometric design is strictly related to the level of a road traffic accident. Numerous accidents are caused by the inappropriate design of road geometric. This study aimed to determine the relationship model of road geometric parameters and accident rate. Jember – Banyuwangi national road was chosen as a location of the study. Five independent variables named the radius of bend, the degree of curvature, super-elevation, widening of the curve, and side freedom were used. Meanwhile, there are three dependent variables modelled, namely EAN (Equivalent Accident Number), accident level, and accident number. The model was obtained and tested using the statistic approach. The results showed that there was a strong relationship between EAN and side freedom. Furthermore, side freedom also proved to have a strong relationship with the accident number. The direction of future study is presented.

INTRODUCTION

Road traffic accident causing deaths has reached a worrying level. In 2016, 1.35 million people died on the road. The World Health Organization (WHO) predicts this trend will be tripled in 2030 (World Health Organization (WHO), 2015). Several factors have been considered as causes of increasing severity of victims of traffic accidents, such as human factors, vehicles, and the environment [1]. Based on Indonesia National Police Traffic Corps data 2015, road and environment were responsible for 3% of accident proportion. Interestingly, many accidents took place on good surface road conditions (accounting for 90%).

Escalating road safety has been becoming a major issue in developing countries. Road engineers believe that proper road design is related to road safety. Meeting the standard should be a critical requirement for road construction. However, Hauer [2] stated that highway standards are limit standards. Instead of concerning the safety design, they are more likely taking the permissible limit of every road design element into account. Although the road environment is not a critical factor, investigating the effects of the road environment on accidents is essential to improve road design. Rizaldi [3] indicated at the national level, road geometric design standard is only concerning design vehicle, design speed, centrifugal force, etc. Meanwhile, safety issues are not a major concern. Moreover, reliable crash data was apparently hard to get. In addition, not only in developing countries but also in developed countries, the accident data quality was primarily questioned in several academic reports. [4]–[6]. Consequently, Bina Marga, as Indonesia highway authority, was unable to improve the safety level of road design.

Jember-Banyuwangi National Road was chosen as a location of the study. It has an important role as a land transportation route for private vehicles, logistics, and tourism. Accident data in Jember shows that road accident in 2013: 907 incidents, road accident in 2014: 934 incidents, road accident in 2015: 871 incidents, road accident in 2016: 954 incidents, road accident in 2017: 1121 incidents, road accident in 2018: 1246 incidents. One of the causes of accidents is the geometric road planning is not following the standard. Road geometric design must comply with Bina Marga standard; therefore, the drivers can feel safe and comfortable when passing through the road. Road geometric design, especially horizontal alignment, has several important components, such as radius of bend, degree of curvature, super-elevation, pavement widening and side freedom.

This study aims to investigate the relationships between a road traffic accident and road geometric design parameters. Understanding the relationship can answer the basic problems of road safety in terms of the road environment.

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LITERATURE REVIEW

Road Accident and Contributing Factors

Several studies concerning road safety have identified the cause of accidents into three main factors, namely human factor, vehicle factor, and road environment factor. The human factor is the leading factor causing accidents. However, some studies stated that the most significant variable causing crashes is traffic volume.

The dangerous driving behaviour factor is a factor that needs to be considered in traffic safety studies. In many cities in Southeast Asia, pedestrians, motorbike riders, motorists, and slow vehicles such as pedicabs, use the road in a chaotic way [7]. In addition, the rapid growth of motorized vehicles, the limitation of safety features for protection, and the unsafe road environment also play an important role in increasing the rate of traffic accidents [8]. Furthermore, behaviour related to speed has been identified as one of the main causes of traffic accidents. The severity of traffic accident victims has a relationship that is directly proportional to speed [9]–[11].

Model Development of Accident Study

Many researchers have studied the accident modelling and prediction. A statistical approach like generalized linear model (GLM) has been generally developed. Meanwhile, a study conducted by Ivan, Wang and Bernardo (2000) a Poisson regression was used to explain the relationship between traffic density, road lighting condition, land use, and accident occurrences. Likewise, Miaou [13] used Poisson regression to investigate the model of truck crashes and highway geometrics relationship.

Meanwhile, the high variability of accident data causes over-dispersion sometimes. Therefore, the Negative Binomial Regression Model (NBRM) was developed as the extension of the Poisson model. NBRM was widely used to develop the model of accident occurrences. [14], [15]

In the recent study, Rizaldi [3] used Zero-Inflated Negative Binomial (ZINB) to develop an accident prediction model. The major finding of the study is road features such as pedestrian facilities, median openings, and speed limits are the significant variables in predicting the accident count. Furthermore, some variables, such as motorcycle percentage, ROW utilization, and intersection type, are also considered significant and have a negative relationship with the accident number.

METHODOLOGY

Data Collection

The data used in this study are primary data and secondary data. The primary data is in the form of geometric parameters of the road. Secondary data in the form of accidents that occur and the average daily traffic volume on the location of the study. Average daily traffic volume data were obtained from the Department of Transportation Jember. Accident data were obtained from the Indonesia National Police Traffic Corps (INPTC). The following are the step of the primary data retrieval process:

1. Determination of curve points: using the help of google maps. Road Geometric Survey
2. Determination of super-elevation, pavement widening, and free area on the inner side of the curve data. The survey used a Global Positioning System (GPS) to determine the coordinates.
3. Calculation of Bend Radius and Curve Degree. Google maps and AutoCad were used to help to calculate this data.

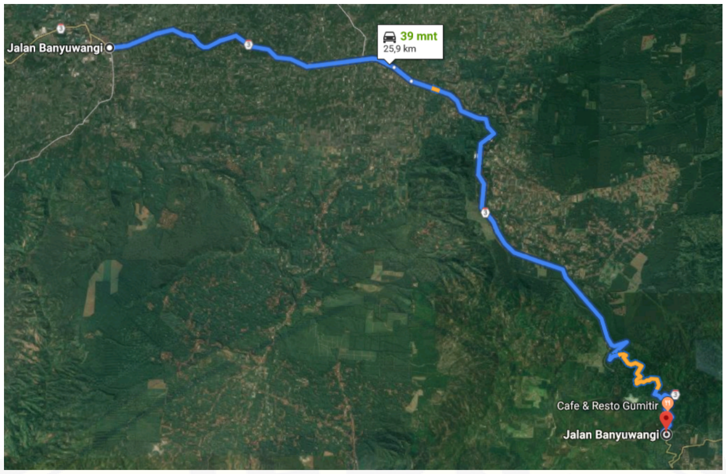

FIGURE 1. Jember-Banyuwangi National Road (case study location)

Data Analysis

The purpose of the analysis phase is to find out the relationship model between curve radius, degree of curvature, superelevation, pavement widening and free area on the inner side of the curve with EAN, level of accident and accident rate. The analysis used in modelling is second-order polynomial regression analysis. The stages of analysis for the relationship are as follows:

1. Calculation of EAN, level of accident and accident rate from accident data on Jember-Banyuwangi National Road;
2. Calculation of curve radius and degree of curvature on maps obtained from google maps;
3. Calculation of superelevation, pavement widening and free area on the inner side of the curve obtained from the survey at the research location;
4. Statistical tests using regression equations to determine the model of the relationship between EAN, level of accident and accident rate with curve radius, degree of curvature, super-elevation, pavement widening and free area on the inner side of the curve.

RESULT AND DISCUSSION

Accident Analysis

The analysis of accident used Equivalent Accident Number (EAN), Level of the accident, and Accident rate method. The calculation of EAN used a weighing scale; fatal accident=12; serious injury=6; slight injury=3; vehicle damage=1.

EAN = 12 (fatal accident) + 6 (serious injury) + 3 (slight injury) + 1 (vehicle damage)

Calculating the level of accident used the formulation stated below:

$$TK = \frac{JK}{(TxL)}$$

Where: TK=Level of the accident; JK=number of accident during x-year; T=time range observation (year); L=length of road (km).

Accident rate mathematically can be calculated as follows:

$$R_{sp} = \frac{(Ax100.000.000)}{(365xVxLxT)}$$

Where: Rsp=Accident rate per-100 million vehicles-km; A=amount of accident; T=observation time (year); L=length of road (km); V=average daily traffic volume.

EAN, Level of accident, and accident rate values for each curve point can be seen in Table 1 as follows:

TABLE 1. Parameters of Accident Analysis

Curve Point	Number of Accidents	EAN	Level of Accident	Accident Rate
Curve 1	14	86	21.2766	44,3260
Curve 2	12	99	11.1840	37,9937
Curve 3	3	21	10.5234	9,4984
Curve 4	3	12	3.2953	9,4984
Curve 5	3	27	8.1112	9,4984
Curve 6	13	112	66.8539	41,1599
Curve 7	7	31	27.3950	22,1630
Curve 8	5	35	6.9247	15,8307
Curve 9	11	110	34.5579	34,8276
Curve 10	5	32	21.5659	15,8307
Curve 11	4	37	10.1103	12,6646
Curve 12	3	21	10.5712	9,4984

Horizontal Alignment Parameters

The total station was used to compare the result obtained from AutoCAD and field. Curve point reviewed for total station survey was curve 8 (Sta 24+400). The curve radius obtained from AutoCAD is 115.2936 m and the curve radius obtained from a survey using a total station is 109.32 m. The difference in the curve radius of the two methods used is 5.18%. The degree of curvature obtained from AutoCAD is 89,707˚; the degree of curvature obtained from a survey using a total station is 88˚. The difference in the degree of curvature of the two methods used is 1,707˚. The results of two data retrieval methods used are not very different. Therefore, the curve radius and degree of curvature for other curves can use AutoCAD.

TABLE 2. Horizontal Alignment Parameters

Curve Point	Curve Radius (m)	Degree of Curve (◦)	Free Area on the Inner Side of Curve (m)	Super-elevation (%)	Pavement Widening (m)
Curve 1	734,5013	12,8334	0,5	14,2857	0,4
Curve 2	342,9875	44,8086	0,8	15,1515	0,2
Curve 3	153,6319	26,5787	1,9	14,9254	0,4
Curve 4	199,1619	65,4779	1	15,6250	0,4
Curve 5	242,0993	21,5946	2,1	16,1290	0,3
Curve 6	86,852	31,8741	1	16,9492	0,2
Curve 7	67,184	54,4782	2	14,4928	0,8
Curve 8	115,2936	89,707	3	16,6667	0,2
Curve 9	77,3847	58,9188	3,5	15,8730	0,4
Curve 10	23,5588	140,9652	1,5	10,3093	2,3
Curve 11	99,2109	57,1287	1,3	15,1515	1,1
Curve 12	39,1847	103,739 7	1,8	11,3636	1,5

Regression Analysis

Regression analysis was used to determine the relationship between the independent variable and the dependent variable. Regression analysis was also used to find out how each independent variable can influence the dependent variable. Independent variables in this analysis are curve radius, degree of curvature, superelevation, pavement widening and free area on the inner side of the curve. The dependent variables in this analysis are EAN (Equivalent Accident Number), Level of the accident, and Accident rate.

Relationship between EAN and Parameters of Horizontal Alignment

Before conducting a regression analysis, a comparison of the coefficient of determination (R^2) was performed to determine the model that is best in the relationship between EAN and parameters of horizontal alignment. Statistical analysis was conducted to determine the most influencing variables on EAN. Second-order polynomial regression produces the best coefficient of determination compared to the other regression models.

TABLE 3. R-square Values of Each Relationship for EAN Variable

No	Relationships	R-square (R^2)
1	EAN and curve radius	0.1437
2	EAN and degree of curve	0.1726
3	EAN and super-elevation	0.1341
4	EAN and pavement widening	0.2374
5	EAN and free area in the inner side of the curve	0.5841

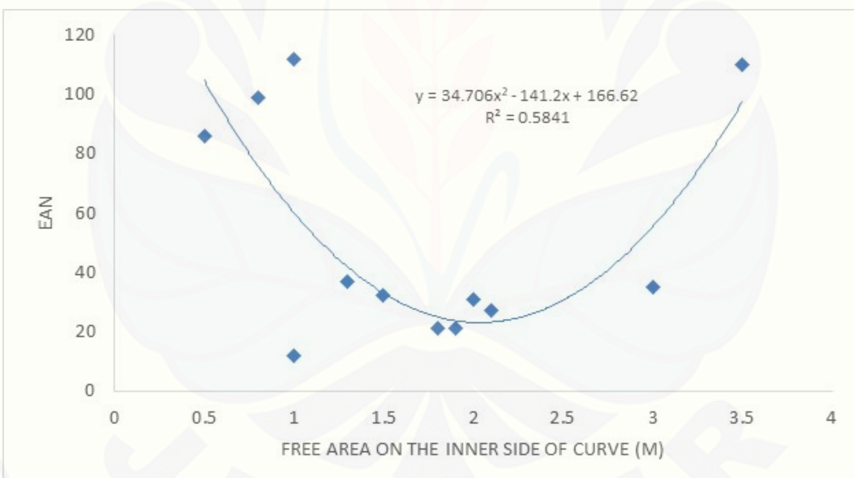

FIGURE 2. Relationship between EAN and Free Area on the Inner Side of Curve

The coefficient of determination (R^2) regression analysis between EAN and free area on the inner side of the curve is 0.5841. It means that free area on the inner side of the curve affects EAN by 58.41%. The graphic trend-line of the relationship between EAN and free area on the inner side of the curve shows that the smaller the free area on the inner side of the curve, the EAN will be greater. However, after reaching a certain point, the EAN trend increases when the free area is larger. It indicates that a larger free area could make the drivers speed up their vehicles; consequently, the increase of crash is seemingly inevitable. EAN shows the smallest value when side freedom is 2 m. A small free area on the inner side of the curve makes visibility not fulfilled so that the drivers who want to overtake the vehicle in front of them will find it difficult to see other vehicles from the opposite direction because it is blocked by objects on the inside of the curve. A large free area on the inner side of the curve makes it easier for the driver to overtake because the driver's view is not blocked, but the large free area on the inner side of the curve also makes the driver overtake at a higher speed.

Determination coefficient was used to decide which variable has a significant effect on the level of accident. Second-order polynomial regression produces the best coefficient of determination compared to the other regression models.

TABLE 4. R-square Values of Each Relationship for Level of Accident Variable

No	Relationships	R-square (R^2)
1	Level of accident and curve radius	0,1494
2	Level of accident and degree of curve	0,0462
3	Level of accident and super-elevation	0,1955
4	Level of accident and pavement widening	0,0492
5	Level of the accident and free area in the inner side of the curve	0,0665

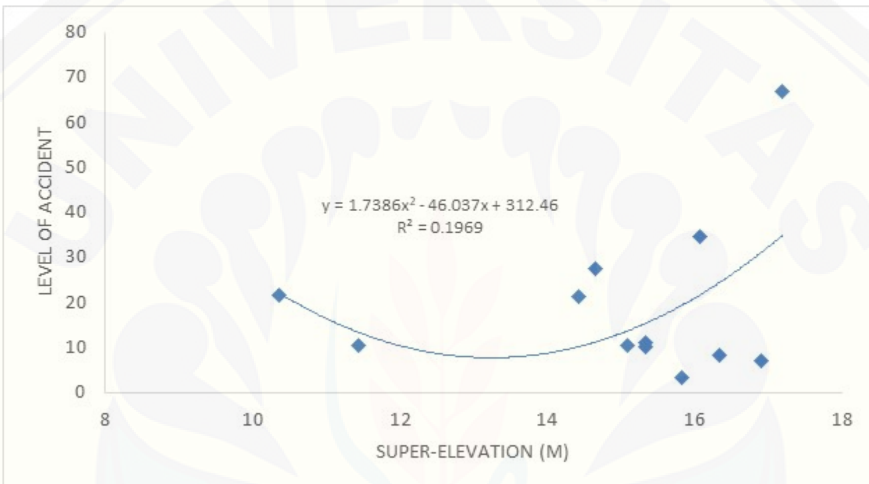

FIGURE 3. Relationship between Level of Accident and Super-elevation

The relationship between super-elevation and level of the accident shows the greatest determination coefficient. It indicates that the relationship between two variables is the strongest among others. However, R^2 is only 0.1969 (under 0.5). It means that 0.8031 (80%) relationship between the level of accident and road geometric parameters is explained by other variables, excluding the variables included in this research.

TABLE 5. Relationship between Accident Rate and Parameters of Horizontal Alignment

No	Relationships	R-square (R^2)
1	Accident rate and curve radius	0,3006
2	Accident rate and degree of curvature	0,1742
3	Accident rate and super-elevation	0,0651
4	Accident rate and pavement widening	0,1947
5	Accident rate and free area on the inner side of the curve	0,6471

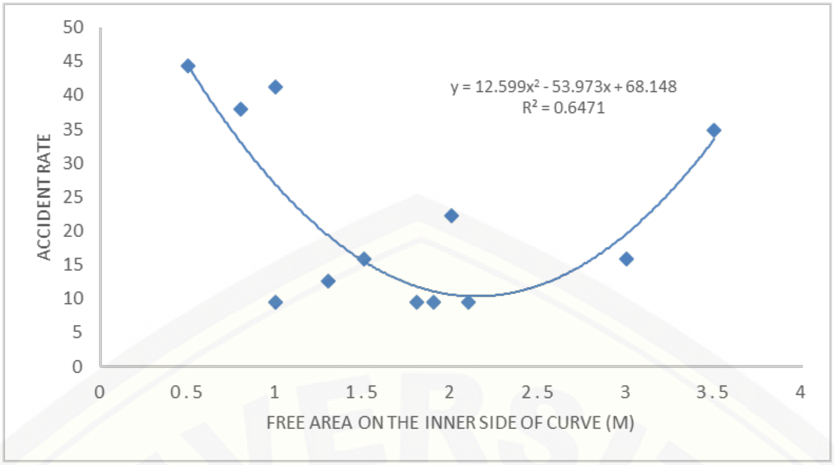

FIGURE 4. Relationship between Accident Rate and Free Area on the Inner Side of Curve

Generally, the trend of the relationship between the accident rate and the free area on the inner side of the curve is similar to the trend of EAN. The graphic trend-line of the relationship between accident rate and free area on the inner side of the curve shows that the smaller the free area on the inner side of the curve, the accident rate will be greater. However, after reaching a certain point, the accident rate trend increases when the free area is larger. It indicates that a larger free area could make the drivers speed up their vehicles; consequently, the increase of crash is seemingly inevitable. Accident rate shows the smallest value when side freedom is 2 m. A small free area on the inner side of the curve makes visibility not fulfilled so that the drivers who want to overtake the vehicle in front of them will find it difficult to see other vehicles from the opposite direction because it is blocked by objects on the inside of the curve. A large free area on the inner side of the curve makes it easier for the driver to overtake because the driver's view is not blocked, but the large free area on the inner side of the curve also makes the driver overtake at a higher speed.

CONCLUDING REMARKS

The result showed that the best model is the second-order polynomial regression analysis. The horizontal alignment parameter that has the closest relationship with EAN is a free area on the inner side of the curve with a coefficient of determination (R^2) of 0.5841 which means that the free area on the inner side of the curve affects EAN by 58.41%. The horizontal alignment parameter that has the closest relationship with the level of an accident is super-elevation with a coefficient of determination (R^2) of 0.1955, which means super-elevation affects the accident rate of 19.55%. The horizontal alignment parameter that has the closest relationship with the number of accidents is a free area on the inner side of the curve with a coefficient of determination (R^2) of 0.6471 which means the free area on the inner side of the curve affects the number of accidents by 64.71%. The type of accident from the data obtained at the curve reviewed is a head-on collision and run-off-road collision. The main cause of the two types of accidents is the inadequate visibility of the curve, which makes it difficult for the driver to pass the curve. The free area on the inner side of the curve that is following visibility is needed to ensure visibility on the curve is fulfilled. Future study can explore the relationship between accident rate and vertical alignment. Furthermore, probability of accident based on road characteristic can be the potential future research while the data is large.

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